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**Beginning to teach chemistry: How personal and academic characteristics of pre-service science teachers compare with their understandings of basic chemical ideas**

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### **Abstract**

Around 150 pre-service science teachers (PSTs) participated in a study comparing academic and personal characteristics with their misconceptions about basic chemical ideas taught to 11-16 year olds, such as particle theory, change of state, conservation of mass, chemical bonding, mole calculations and combustion reactions. Data, collected by questionnaire, indicate that despite all PSTs being regarded technically as “academically well-qualified” for science teaching, biology and physics specialists have more extensive misconceptions than chemists. Two personal characteristics, PSTs’ preferences for teaching as a subject “specialist” or as a “generalist” teaching all sciences and their self-confidence for working in these two domains were assessed by responses to Likert scale statements. Proportionately more biologists tend to be “super-confident” generalists, while more physicists were specialists anxious about outside specialism teaching. No statistically significant relationships between personal characteristics and misconceptions were found, suggesting that chemistry may be being taught by confident PSTs with poor understandings of basic ideas. Further, these data suggest that attending to PSTs’ personal characteristics alongside other components of a teacher’s professional knowledge base may contribute to creating more effective science teachers. The paper presents a novel way of considering PSTs’ qualities for teaching that offers potential for further research and initial teacher training course development.

### **Introduction**

How best to ensure pre-service science teachers (PSTs) have the science knowledge required at appropriate levels for secondary school teaching is debated internationally (Abell, 2000). Cochrane & Jones (1998) indicate that an undergraduate degree in a science is regarded implicitly as providing sufficient basis of scientific knowledge for teaching. The UK system, the locus for this study, requires applicants for postgraduate teacher education to hold an undergraduate degree in a science subject in order to teach all sciences to 11–14s, and, in many secondary schools, to 14–16s. However, the numbers of graduate chemists and physicists entering the profession is low relative to biologists: a recent UK-based study (Moor, Jones, Johnson, Martin, Cowell & Bojke, 2006) showed that 25% of around 2800 science teachers held biology or biology-related degrees, 16% chemistry degrees and 10% physics degrees, while about 47% possessed degrees in other sciences or general sciences and 2% held no science degree at all. This imbalance has contributed, in many state-funded secondary schools, to science teachers teaching all sciences to 11–16s, in part because insufficient numbers of chemistry and physics specialists are available to teach these as separate subjects to 14 – 16 year olds. Debate has ensued about the relative merits of teaching science as three separate disciplines, or one subject. Teaching science as three separate disciplines, in particular ensuring physical sciences are taught by specialists, is heavily promoted by organisations such as the Campaign for Science and Engineering (CASE):

“Children need to be taught by specialist [science] teachers. Teachers’ qualifications predict teaching quality and are the second greatest predictor of performance in physics after pupil ability” (p 2, CASE 2007)

and the Royal Society of Chemistry (RSC) :

“The best teachers are those who have specialist subject knowledge .... The RSC believes that young people deserve to be taught the sciences by subject specialists” (RSC, 2004)

One focus for this paper is to present aspects of the chemical content knowledge held by PSTs and hence examine the extent to which these claims can be justified. In the UK, although being taught by specialist chemistry teachers is recognised as desirable, in practice this is prohibited by poor recruitment of chemists and physicists into secondary science teaching relative to biologists. Permanent solutions to raising the numbers of physical science graduates entering teaching remain elusive. The pragmatic result for many graduates entering teacher education is that they need to teach all aspects of National Curriculum science (DfES, 2006) to 11 – 16s, rather than teaching all sciences to 11 -14s and their specialist subject to 14 – 16s. This study explores the extent to which the current criterion, possession of a “good” science degree, provides adequate subject matter knowledge for teaching basic chemical ideas to this level.

A second goal is to investigate PSTs’ personal characteristics, in particular their confidence for outside specialism teaching, and assess the extent to which self-perceptions of confidence align with the quality of their chemical knowledge about basic concepts. This follows on from earlier work by Author 1 (2009). The initial study investigated the strategies trainee science teachers use in developing their science subject matter knowledge for teaching, and whether they perceived themselves to be more “successful” when teaching the science subject in which they held a degree (“within” specialism), compared to other

sciences (“outside” specialism). Findings were counter-intuitive – a number reported greater success teaching outside specialism, partly because help from school based mentors contributed positively to planning lessons and subject knowledge development. Further, PSTs responded to a paired-statement Likert-scale questionnaire (used in this study, see below, p 12 - 14) probing self-confidence and preferences for teaching in the contrasting domains. These revealed that some had a “super-confident” stance, believing they could teach any subject effectively. Others, in contrast, were “anxious”, wishing to “revise” subject knowledge extensively prior to teaching. Preference stances showed some PSTs were “generalists”, prepared to teach any science. An opposite position, named “specialists”, was expressed by others, who seem to prefer to teach the science in which they hold degrees. Interviews showed that some “super-confident” PSTs revealed their stance to be misplaced, as they realised they could not teach all sciences successfully from the outset. Within specialism lessons were cited as especially problematic, due to difficulties in selecting appropriate material and over-pitching lessons. “Anxious” PSTs reported working hard to address subject knowledge weaknesses, feeling concerned about answering student questions. The extent to which respondents referred to subject knowledge issues in relation to their emotional concerns prompted the present study. We wanted to know if there is a correlation between levels of content knowledge for chemistry and confidence for teaching different sciences. Similar work linking personal attributes with aspects of preparation for science teaching at elementary (primary) level has been carried out (see Jarrett, (1999); Smith, (1997); Tosun, (2000)). For example, Gostev (2008) found no correlation between individual pre-service primary (elementary) school teachers’ science content knowledge and confidence for teaching science. He reports that those with the lowest science content knowledge test scores believed themselves to be moderately or highly confident to teach science, while others with good content knowledge scores expressed low confidence. However, we noted that links between personal attributes and subject matter knowledge have not yet been investigated at high school (secondary) level. One reason for this may be the existence of an implicit assumption that possession of a specialist degree in a science subject infers confidence for teaching that subject to secondary aged students. Grossman, Wilson and Shulman (1989) point out deficiencies in this viewpoint, as degrees vary in content and quality; and degree course content does not relate directly to school subject content. The position for science is potentially more serious: as indicated above, the current recruitment situation means that chemistry, will, in many state-funded schools, be taught by teachers with limited post-16 education in the subject. This fact suggests investigating connections between misconceptions in chemistry and personal confidence for teaching different sciences is worthwhile. Do biology graduates, who comprise the majority of initial teacher education entrants, feel as confident teaching other sciences as their own subject? And can we confirm that their levels of misconceptions are similar to those of chemistry/ physics graduates entering teacher education? As Gostev indicates (2008, p 4697), a trainee presenting as a highly confident individual may not be in the strongest position to become a successful teacher. This was confirmed by Author 1 (2009). At the heart of this paper lies the extent to which science graduates are aware of their misconceptions and how these influence their science teaching. The present paper notes implications for teacher education arising from the findings.

## **Context for the study**

The study took place in a university in northern England, using PSTs attending an initial teacher education course referred to as the “Postgraduate Certificate in Education” or “PGCE”. Obtaining this qualification is the most popular route for obtaining a post as a teacher in UK state-funded secondary schools. The intensive, full-time course requires nine months to complete, running from September to June each academic year. The course involves completion of 24 weeks teaching practice in two different schools together with 12 weeks higher education institution- (HEI) based work. Participants are assessed against nationally determined standards for Newly Qualified Teachers (NQTs), referred to as the “Qualified Teacher Status” (QTS) standards (Training and Development Agency, 2008) and the university’s own academic requirements. Pedagogical and subject knowledge training is provided mainly in the HEI-based period. PGCE courses differ in the exact method and timings of course content – at this university, PSTs attend subject knowledge sessions totalling about forty-five hours of instruction in all sciences. Topics covered include earth and space, genetics, chemical changes, substances and materials, properties of materials, electricity, forces, ecology, energy and waves. Other science-specific sessions, also of around forty-five hours duration, train aspects of working as a science teacher in the UK system, including opportunities to develop knowledge about assessment methods, the National Curriculum, planning lessons, progression in learning, behaviour management, science investigations, assessment methods, fieldwork, learning theories, teaching post-16, sex education and handling sensitive issues. Teaching practice allows PSTs to develop classroom-based skills gradually, under supervision. PSTs are allocated to schools up to 80 km (50 miles) from the University. The first teaching practice, from October –December, begins with three days per week in school, with the remaining two days in the University for four weeks. This allows PSTs time to get used to school routines, gather information about classes, observe teachers and classes and to teach sections of lessons, building up to whole lessons. This practice concludes with four five-day weeks in school. During this time PSTs have responsibility for three or four classes, equivalent to 50% of the usual workload for a science teacher, amounting to about 11 hours teaching per week. In some circumstances, such as an individual making slow progress or a class having highly specific needs, lessons may be taught with another teacher, as a team. The usual expectation is that a PST will take responsibility for planning and delivering the vast majority of lessons assigned to him/her by the end of the placement. The second teaching practice is held from late-January through to May in a different school. The aim of this placement is to consolidate development of teaching skills, with the emphasis on becoming an independent classroom teacher. The practice builds towards PSTs showing understanding of progression in learning, planning teaching over an extended period, methods of assessing students’ needs and analysis of learning. The placement begins with four weeks split 3:2 between school and University to allow time for orientation and observation, building to PSTs taking overall responsibility for teaching up to two-thirds of the typical workload for a science teacher, amounting to 14-16 hours of teaching each week. Normally, a trainee will teach a wider range of classes in this placement than in the first teaching practice. In both schools PSTs are provided with individual school-based mentors, always experienced teachers, who assist in monitoring progress against the QTS standards. Their teaching is observed regularly by the mentor, other school staff and a University tutor - feedback on teaching combined with self-reflection provide important input into PSTs’ ongoing development.

Opportunities available for teaching specific sciences during the teaching practices vary. The over-riding principles are that while studying on a science PGCE, participants will gain experience of teaching all sciences to 11- 14s and a specialist subject, biology, chemistry or physics to 14 – 16s. In practice, many secondary schools employ science teachers to teach all sciences to 14 – 16s, as stated above: at any point during the two teaching practices, therefore, a pre-service teacher may be expected to teach his/her specialist subject, biology, chemistry or physics to one class of 14 – 16s, and a science in which s/he does not have expertise to a different group of the same age. Overall broad parity of experience for all is achieved, as school staff are aware of the criteria that need to be met in PSTs' teaching timetables. Thus, in practical terms, we distinguish between "within" and "outside" specialism science teaching. In order to handle the range of science material they may be expected to teach, the University in this study expects PSTs' functional knowledge in all sciences to match that required to obtain a good grade in the General Certificate of Secondary Education (GCSE) science (examination held at the age of 16), in addition to being a trained specialist with a science degree. As indicated above, specific HEI-based sessions are offered to help address science knowledge needs and PSTs will work independently on subject knowledge to meet the requirements of their teaching timetables.

To gain a place on the programme, PSTs must meet government-set criteria, including possession of a "good" degree in a National Curriculum subject (see <http://www.tda.gov.uk/Recruit/thetrainingprocess/basicrequirements.aspx> accessed September 2009). Degree class is a widely accepted indicator of a potential teacher's academic ability. An "academically well-qualified" trainee for teaching purposes possesses a degree classified at 2:2 (lower second class honours) or above<sup>1</sup>. PSTs with a diverse range of science degrees are accepted on to the PGCE: those classified as specialist "biologists" in this study held degrees in biology, genetics, biomedical sciences, environmental science, ecology, physiology or marine biology. Similarly, "chemists" held degrees in chemistry, biochemistry or another chemistry-related subject, namely geology, pharmacology, forensic science, colour chemistry or environmental chemistry; and "physicists" degrees were in physics, astrophysics, astronomy, mechanical engineering or optometry.

To date, selection criteria focus on PSTs meeting academic standards and possessing specific GCSE (or, for candidates educated outside England, Wales and Northern Ireland, their equivalent) qualifications. PSTs who meet academic criteria are invited for interview during which potential for teaching is assessed. Teacher educators are aware that personal characteristics such as flexibility in thinking and resilience in handling difficult situations are good indicators for success. Other characteristics such as self-confidence and attitudes or preferences for working as a specialist or generalist science teacher are not, as far as the authors are aware, probed in UK selection processes, and certainly not during selection at the University in the study.

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<sup>1</sup> Four categories of "honours" are used in the UK to describe undergraduate degrees: the highest, normally awarded to around 10% of a cohort, is "First class" (1<sup>st</sup>). Students awarded 1<sup>st</sup> class honours normally achieve 70 – 75% in a high proportion of their final examinations and have good academic records from previous years of study. About 40% gain "Upper second class honours" (2:1), the next highest category. Approximately 30% will be awarded "Lower second class honours" (2:2) – at many UK universities only students with these three categories of undergraduate degree are admitted to postgraduate courses. About 20% are awarded "Third class honours" (3<sup>rd</sup>). Students whose work does not meet honours standard are awarded "pass" or "ordinary" degrees.

**Rationale, theoretical foundations and research questions**

In the present system, as explained above, all PSTs teach in two domains: “within” and “outside” specialism, depending on how a curriculum topic aligns with degree subject. PSTs’ scientific backgrounds mean their science knowledge for teaching outside specialism is likely to be weaker than that for their specialist subject. For example, some specialist biologists may not have studied physics since they took their 16+ examinations; chemists and physicists similarly may have studied little or no biology since then. We assume PSTs vary in the extent to which they engage with the different demands placed on their subject knowledge and consequently may prefer working as a “specialist” or being a “general” science teacher. Their preferences for these roles may relate to their self-confidence about teaching sciences not learned since secondary school.

The study adopts the Shulman (1987) paradigm, perceiving subject knowledge as one aspect of a teacher’s knowledge base, transformed for students’ benefit using pedagogical content knowledge (PCK). Teachers’ science subject knowledge is embraced in “subject matter knowledge” (SMK, Tamir, 1988). SMK is generally agreed to be an overarching term, comprising a number of components, each of which influences teaching. Abell (2007) notes that Shulman’s view of SMK derived from Schwab (1964), who identified two types: substantive and syntactic. Substantive knowledge is the organisation of concepts, facts, principles and theories, while syntactic knowledge is the rules of evidence and proof used in making claims about new knowledge in the subject. Shulman and co-workers added two more components (Grossman, Wilson & Shulman, 1989). They suggested “content knowledge” represents the facts, procedures and concepts of a discipline (thus limiting substantive knowledge to principles and theories), and added beliefs about the subject. Later workers such as Cochrane & Jones (1998, p 708) adopt a similar four component structure: they list content knowledge (facts and concepts); substantive knowledge (explanatory structures or paradigms); syntactic knowledge (methods and processes by which new knowledge is generated); and beliefs about the subject matter (learners’ and teachers’ feelings about various aspects of the subject). Of particular interest here are PSTs’ conceptual understandings of basic chemical ideas normally taught to 11-16s – thus our study explores aspects of teachers’ content knowledge (CK) for teaching chemistry.

Teacher beliefs and attitudes are thought to exert significant influence on instructional practices (Jones & Carter, 2007). Difficulties of definition of attitude and belief arise, not least because, as Jones and Carter indicate (2007, p 1068) the terms are often used interchangeably. We follow the lead of these authors in situating attitudes as components in a person’s belief system, thus accepting “beliefs” as encompassing self-efficacy, epistemologies, attitudes and expectations. Relative to work on SMK, these areas are less well-researched and understood. This study attempts to add to our knowledge of aspects of pre-service teachers’ internal belief systems by exploring preferences and confidence for teaching as “specialist” or “generalist” science teachers. We are unaware of other studies that have probed this precise point. Our choice is to define these as “personal characteristics” that may impact on PSTs’ classroom activities.

Our research questions are:-

1. What misconceptions about basic chemical ideas are held by pre-service science teachers (PSTs)?



2. In what ways do PSTs' academic and personal characteristics relate statistically with their misconceptions?

We may reasonably expect that PSTs with degree-level education in chemistry will possess fewer misconceptions about basic ideas than those with backgrounds centred mainly in biology or physics. A second reasonable hypothesis is that PSTs vary in the extent to which they regard themselves as “specialist subject” teachers preferring to teach within specialism or as “general” science teachers, content to teach all sciences. Their self-confidence for working within and outside specialism is also likely to vary and may impact on their preference for either role. The author's earlier paper (Author 1, 2009) compared the prevalence of these characteristics against subject matter knowledge development strategies. This paper takes a similar approach, affording close inspection of PSTs' content knowledge in chemistry and any statistical relationships with preferences and confidence data.

## **Literature review**

### ***Teachers' misconceptions of science topics***

School students' misconceptions about basic chemical ideas such as particle theory, chemical bonding, conservation of mass in reactions, combustion and mole calculations are well-documented (for a review see Kind, 2004). That these often develop in early- to mid-teenage years and are carried through into post-16 chemistry studies is also known (Barker & Millar, 1999; Barker & Millar, 2000). More recently, topic-specific studies have indicated the impact pre-16 chemistry has on post-16 learning. Taber (2009), for example, showed that college students' (16 – 18 year olds) understanding of the relative stability of chemical bonds relies on their applying the “octet rule”, often learned in pre-16 chemistry, to all situations without exception. This generates faulty reasoning, such as that  $C^{4+}$  and  $C^{4-}$  are more stable than carbon atoms. Faulty understanding of science topics among teachers has also been probed. Calik, Ayas & Coll (2007) found that pre-service teachers hold a wide range of misconceptions about solution chemistry, but responded by changing their thinking when given appropriate opportunities. In a US-based study investigating a broad range of science ideas, Rice (2005) asked around 400 pre-service and about 70 in-service primary (elementary) school science teachers over a ten year period to answer ten simple science questions, including three on chemical topics. She reports that 74% knew that an electron is smaller than an atom; only 4% could correctly explain what a “molecule” is; and that more than 50% suggested the boiling point of oxygen was 100 °C. Rice describes the results as “very troubling”, noting that poor knowledge levels means “the quality of instruction and potential for student learning are compromised” (p 1063). Links between teachers' SMK and teaching skills have been investigated in a number of studies, reviewed next.

### ***Connections between SMK and teachers' classroom practice***

Researchers have probed the extent to which teachers' possession of erroneous scientific ideas influences their teaching. For example, working in South African schools, Sanders (1993) found that teachers had erroneous ideas in four conceptual areas about respiration, noting that these needed correction in order to ensure students learned effectively. She connected teacher-held misconceptions about respiration with those of the final year school students taught by the teachers in the study. K  p  ly  , Heikkinen & Asunta (2009) studied

teachers' SMK for teaching photosynthesis and plant growth. They report that content "experts" were more able to handle content structure in planning lessons and handling students' conceptual problems. In a study linking quality of SMK in chemistry to teachers' PCK explicitly, Kaya (2009) showed that trainee secondary science teachers vary considerably in their knowledge and understanding of ozone layer depletion. Those with higher quality understanding of key issues demonstrated more appropriate PCK, including better understanding of strategies that could be used to diagnose students' preconceptions about the topic (p 980). These, and other studies (such as those reviewed by Abell, 2007; Van Driel, De Jong & Verloop, 2002; Davis, 2003; Markic, Valanides & Eilks, 2006; Carlsen, 1993) offer support for Carre's view that

"The more you know about science, the more you will be able to provide a framework to help children think in scientific ways; in so doing you will also represent the subject with integrity" (1998, p 103)

Other studies probe links between SMK and PCK from a teaching skills perspective. These indicate that successful teachers, regarded as "effective" in terms of awareness of students' difficulties, and/or using active learning strategies, demonstrate good quality SMK for the topic or subject being taught. For example, Hashweh (1987) probed teachers' prior knowledge of specific biology and physics topics with the aim of tracing the impact of this on their teaching. Hashweh showed that teacher subject knowledge influenced the ways in which a written curriculum shown through textbooks was transformed into an enacted curriculum for students – where their knowledge about a topic was good, such as when teaching within their specialism, teachers were found to detect students' preconceptions; deal effectively with general class difficulties; and interpret students' correct comments appropriately. Similar results were found by Carlsen (1993) who explored the SMK and teaching of four novice biology teachers, working in their specialism. He found that when teaching topics they knew well teachers more often posed high level questions and used more interactive instructional strategies. Sanders, Borko & Lockard (1993) studied similarities and differences in the practices of experienced science teachers working within and outside specialism. Within specialism, teachers were able to pick up on students' questions and unexpected events, creating positive learning outcomes. When teaching outside specialism, the authors note that these experienced practitioners behaved "like novice teachers" (p 723), having difficulty answering students' questions and sometimes lacking consistency in their lessons. The authors note that content knowledge limitations were particularly evident in the outside specialism lessons. Gess-Newsome and Lederman's (1995) study of experienced biology teachers generated similar findings, concluding that "the level of content knowledge had a significant impact on how content was taught" (p 317). These authors agree with Käpylä et al (2009) in noting that a minimum level of SMK is needed in order for teachers to be effective (p 1408) but point out that comparing experienced and novice teachers using the same expectations and criteria is perhaps unfair.

Abell (2007) suggests that SMK has some impact on practice, but this may be mediated by other types of teacher knowledge. Gess-Newsome (1999) goes further, noting that teaching itself may be a "powerful tool" in forcing changes to a teacher's practice, by "moving knowledge from passive reception to active processing" (p 64). Thus, the experienced teachers working outside specialism in studies reported above had no option but to revert back to "novice" practices perhaps because their SMK in the unfamiliar subject required active processing through teaching. However, Gess-Newsome points out that "learning

from experience can be difficult to predict and may not always result in best practice” (p 64).

### ***Science teachers’ self-efficacy and self-confidence***

Learning to teach requires placing oneself in a “high risk” situation in which “success” relies on learning a wide range of skills. Novice teachers require optimism and resilience to deal constructively with difficult classroom situations or poor learning outcomes, believing that s/he can/will improve. Thus, PSTs require high self-efficacy - believing themselves capable of performing in a certain manner to achieve specific goals, and the self-confidence to carry this through. Teachers’ self-efficacy and self-confidence are personal perspectives on experiences and hence fall under the umbrella heading of “beliefs” (Pajares, 1992). He states:-

“...one’s personal predispositions are not only relevant, but, in fact, stand at the core of becoming a teacher” (p 322).

Kagan (1992) also places strong emphasis on the role(s) played by teacher beliefs:-

“The more one reads studies of teacher belief, the more strongly one suspects that this piebald of personal knowledge lies at the very heart of teaching” (p 85)

Evidence linking high self-efficacy to positive attitudes surrounding teaching has been collected from various studies. For example, Bandura, Barbaranelli, Caprara & Pastorelli (1996) report that high self-efficacy is linked to positive attitudes that help individuals manage challenging tasks, such as learning to teach. Woolfolk Hoy (2000) notes that “mastery experiences”, or the perception that a performance has been successful, during training and induction are powerful influences on developing high self-efficacy as a teacher (p 2). She found that self-efficacy rose during initial training, but fell with actual experience as a teacher, a finding probably allied to the level of support received during these periods of a teacher’s working life.

The present study explores PSTs’ beliefs about the specific situation of teaching science outside specialism – the extent to which a trainee perceives him/herself as a “general” science teacher or a “specialist” and the confidence s/he has for fulfilling these roles may be significant to his/her success. This topic has received relatively little attention from researchers. Dillon, Osborne, Fairbrother & Kurina’s (2000) wide-ranging study about teachers’ needs and views found differences in confidence levels for teaching biology, chemistry and physics to 14 – 16s among 600 secondary science teachers. While 60% claimed confidence for teaching chemistry, only 50% did so for physics and 52% for biology (p 29- 30). Links to qualifications were also explored. Positive correlations were found between possession of degree level qualifications and confidence for all three sciences, that is, holding a degree in biology/chemistry/physics correlated with confidence for teaching the subject. Negative correlations were found between those holding biology and physics qualifications and teaching the “other” science – biologists expressed lack of confidence for teaching physics and vice versa.

More specific studies include that of Millar (1988), who linked the depth and extent of secondary science teachers’ knowledge of physics to their confidence for teaching the subject. He reports that when asked to teach physics as a non-specialist, teachers’

backgrounds in the subject influenced their confidence levels, often in an unrealistic way. Some teachers anticipated much more difficulty with physics content knowledge than they found in practice, suggesting low confidence was unjustified. Negative perceptions about teaching physics are also apparent among primary teachers. Johnson & Ahtee (2006) studied the attitudes, subject knowledge and PCK of pre-service primary teachers in England and Finland related to a physics activity. They found that teaching physics was viewed more negatively among this group than science generally, maths and mother tongue language and claim a link between poor attitudes towards physics and lack of confidence for teaching the subject. In their study of primary teachers Appleton & Kindt (1999) showed that lack of confidence for teaching science was associated with limited background knowledge, while self-confidence was negatively affected by anxiety about answering children's subject-related questions. In earlier work, Appleton (1995) found that providing primary teachers with opportunities to learn more science did not necessarily ensure positive attitudes about teaching the subject. He found pre-service teachers' confidence levels related to science teaching did not change as much as expected before and after exposure to a science education unit. Appleton concluded that content alone does not influence teachers' learning. One reason for this may be that beliefs about teaching and self-perceptions in relation to the role of a teacher form early and are resistant to change (Kagan, 1992). Ekborg's (2005) longitudinal study offers support for this – she investigated the formation of ecology concepts among trainee science teachers. Ekborg reports that PSTs don't develop conceptual understanding necessary to engage with the issue, but learn science content from their personal notions of a primary teacher's role. Thus, in learning to teach, personal interpretations of what a teacher does and perhaps how well an individual believes him/ herself capable of fulfilling this role may influence their level of success – provision of “a course” to help address perceived SMK needs may not be enough.

That teaching involves emotional investment is clear from various studies. For example, McNally (2006) studied pre-service teachers learning to teach science investigation skills. He notes that new teachers' “undeveloped knowledge and emotional vulnerability are not unduly exposed” (p 434). McNally suggests that developing confidence alongside expertise through a learning cycle set in motion during initial teacher education may help. Positive attitudes and the ability to cope with difficult circumstances have featured in several projects, three of which are reviewed here. First, Lumpe, Haney & Czerniak (2000) developed a Context Beliefs About Teaching Science (CBATS) instrument designed to assess the extent to which teachers beliefs about aspects of their work were positive or negative. A majority of experienced teachers were found to possess “robust, modest and tenacious” belief patterns (p 285) which helped sustain them in difficult circumstances. A minority held “vulnerable, fragile and self-doubting” beliefs, which, the authors noted, may lead to these teachers leaving the profession at an early stage. Second, Gurvitch & Metzler (2009) found that trainee physical education teachers developed higher levels of self-efficacy for teaching when offered opportunities to face challenges, cope with these and overcome adversity. They associated good teacher efficacy with a tendency or interest in trying out various approaches and implement innovation. Third, the role played by resilience in enhancing retention of teachers was investigated by Le Cornu (2009). She discusses in general terms how an effective mentor, peer support and explicit teaching of skills and attitudes can help develop teachers who can withstand classroom challenges. Thus, evidence points to personal qualities such as confidence and resilience as being important factors in teacher success. Besides these obvious positive qualities, Merz & Swim (2008) add an additional dimension, discussing the role played by “defensive pessimism” in certain individuals, who set low expectations for themselves in situations

they perceive as “risky”. Merz and Swim found that although this may seem a negative quality, teachers with this stance could perform well, because they could harness their anxiety to motivate themselves to avoid the possibility of failure. Being a pessimist did not detract from being an effective teacher.

### **Methodology and Data Analysis**

The study adopts mixed methods (Merriam et al, 2002). As such, using a new combination of instruments with students drawn from one institution, the study must be regarded as exploratory in nature. Established probes in the form of a questionnaire (Barker, 1994) were used to investigate misconceptions in five areas of chemistry: particle theory and change of state (both usually taught to 11-14s); conservation of mass; chemical bonding; mole calculations and open system (combustion) reactions (topics usually taught to 14 – 16s). The misconceptions probes, some based on extant research, were validated at the time these were devised by discussion with education and chemistry colleagues and thorough pilot testing (see Barker, 1994). Questions on the same topic were grouped together to create five “sub-tests” as shown in Appendix 1. Each diagram, explanation or multiple choice response was given a separate code for entry against each trainee’s anonymous code number in Statistical Package for Social Sciences (SPSS, version 14.0). Standard deviation, standard error and mean scores were calculated and presented in Table 2. Significant differences in scores between the three trainee specialist scientist groups, namely physicists, chemists and biologists were calculated and appear in Table 2 where appropriate. Other statistical data were calculated using standard SPSS functions and are reported where appropriate below.

PSTs’ personal characteristics were collected using a five-point Likert-scale questionnaire. The questionnaire comprised a total of fourteen statements exploring different aspects of content knowledge, strategies used to acquire content knowledge and confidence for teaching within and outside specialism. The questionnaire and style of the statements was based on the approach taken by the Science Teaching Efficacy Belief Instrument (STEBI, Riggs & Knochs, 1990). This 25-item questionnaire explores teachers’ views about general matters relating to primary science teaching. However, as such, STEBI does not differentiate between teachers working within and outside specialism at secondary level, nor does it explore teachers’ preferences for working in these domains. Hence, a new set of statements was devised for the secondary context. Responses to two pairs of statements, referred to as the “Preference” and “Confidence” pairs are reported here. These are categorical variables – as shown below (Figures 1 and 2) logical combinations of responses give rise to categories into which PSTs can be placed. PSTs’ perceptions were confirmed by interview data collected from fifteen random volunteers, extracts from which are reported below and in an earlier paper (Author 1, 2009). The interview protocol has been reported earlier (Author 1, 2009). Interview extracts are used here to support questionnaire findings.

The Preference pair relates to PSTs’ preferences for teaching as a subject specialist or as a general science teacher:-

- I prefer to teach topics in my specialist area – abbreviated to “prefer to teach specialism”, or PTS
- I am pleased to teach topics in all areas of science – “pleased to teach all” (PTA)

Analysis and coding of responses to the pair statements were carried out by examining possible logical outcomes. Over 90% of PSTs' responses to the preference pair (reported in Table 3) were categorised as in Figure 1:-

Statement	Responses			
PTS	Agree/strongly agree	Agree	Neutral / Agree	Disagree/strongly disagree
PTA	Disagree/strongly disagree	Neutral	Agree / Strongly Agree	Agree/strongly agree
Category	Positive specialist (PS)	Neutral specialist (NS)	Neutral Generalist (NG)	Positive generalist (PG)

Figure 1: Categorisation of preference pair responses

A small proportion (11 PSTs) responded “neutral”, “strongly agree/agree” or “strongly disagree/disagree” to both statements. These cannot be analysed as indicating any meaningful preference. A “neutral” / “neutral” response effectively indicates no preference at all, for example. These were not included in further analysis.

The Confidence statement pair is:-

- I am less confident when I teach outside my specialist area – abbreviated to “less confident outside” (LCO)
- I do not need to teach my specialism to feel confident as a teacher – “do not need specialism” (DNS)

This pair explores the extent to which a trainee feels confident about teaching outside his/her specialist subject. Figure 2 shows the responses (reported in Table 4) given by over 90% of PSTs to the confidence statement pair:-

Statement	Responses			
LCO	Agree/strongly agree	Agree / Neutral	Disagree	Strongly disagree
DNS	Strongly disagree	Agree/ Neutral	Neutral/Agree	Strongly agree
Category	Anxious (A)	Working Confident (WC)	Confident (C)	Super-confident (SC)

Figure 2: Categorisation of confidence pair responses

“Super-confident” (SC) PSTs gave strongly positive responses to DNS and strongly disagreed with LCO. Respondents in this category are clearly stating that their confidence levels were high, regardless of the science they taught. “Confident” (C) PSTs show the same response pattern as “super-confident” PSTs, but are less strident, agreeing with DNS and disagreeing with LCO. PSTs classified as “Working confident” (WC) agreed with or were neutral to LCO and agreed with or were neutral to DNS. Fourthly, some PSTs agreed

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with LCO, and disagreed strongly with DNS. This category, named “Anxious” (A) appeared to indicate they do need to teach their specialism to feel confident as a teacher, exhibiting anxiety about outside specialism teaching. Fourteen PSTs’ responses did not fit into these categories, for example, those who disagreed strongly with both statements whose confidence level could not be determined.

The fact that so few PSTs (11 and 14 respectively) in a total of 152 responded in ways that could not be clearly categorised as indicated above suggests that a majority read and responded to the paired statements as anticipated. Interview data (reported earlier, Author 1, 2009, and below) supports the findings from the Likert scale questionnaire. Thus, as far as we can determine, the data obtained are reliable.

Background information about PSTs’ degrees in science, possession of any higher degrees, age, gender and teaching specialism were collected and provide contextual information.

### **Sample**

All respondents were taking the one year postgraduate teacher education course (PGCE) described above (see Context): data were collected annually from PSTs commencing their courses in September 2005 – September 2008. They are reported as one cohort.

179 PSTs responded to the misconceptions probes. These data were collected at the start of the course prior to any withdrawals taking place. The PSTs were divided between the four years of the study as follows: 38 (2005-2006); 42 (2006-2007); 47 (2007-8); 52 (2008-9).

Personal characteristics data were collected three months after the misconceptions data. This was done to avoid the possibility that PSTs would adjust their responses, for example, responding more negatively about outside specialism teaching, as a result of perceiving they had responded poorly or struggled with aspects of the misconceptions questionnaire. Also, some of the statements on this questionnaire made sense in the context of teaching – collecting these prior to teaching would also influence responses. At the time the personal characteristics data were collected, PSTs had carried out a short period (20 days) of full-time teaching practice, together with four weeks part-time in schools split 3:2 between the University and school (see Context). Over the four years of the study 27 PSTs (six or seven PSTs per year) had withdrawn by the time of this data collection. Thus, the maximum number of responses to the Likert scale questionnaire is 152.

## **Results**

### ***Academic background and age distribution***

Table 1 shows the PSTs’ backgrounds. Overall, the sample of 179 science PSTs is skewed towards females (54%:46), biologists (55%:27:18, biologist chemist, physicist) and those aged 21 – 25 (60%). These proportions showed little variation in all four data collection years. Anecdotal evidence suggests such characteristics are typical of graduates attending UK postgraduate science teacher education courses at a number of universities at present. Table 1 indicates that about 90% of the sample meets this criterion. Eighteen PSTs held other UK degrees or qualifications from elsewhere; seven did not provide these data.

[INSERT TABLE 1 ABOUT HERE]

Comparing PSTs by scientific discipline suggests that the chemists were the least well-qualified group in terms of their academic achievement overall, with 53% (25/47) holding degrees in the lowest two honours categories of 2:2 or 3<sup>rd</sup>, while only 48% of physicists (15/31) and 31% of biology graduates (29/94) did so. Conversely, 66% of biologists, 45% of physicists and only 38% of chemists held degrees in the highest two honours categories. 20% (N=36) of the overall sample possessed higher degrees (Masters or Doctorate).

The average age of the PSTs was 26. The high proportion of 21 – 25 year olds suggests that a majority chose teaching as a first career: in the UK most students complete their first, or “Bachelor” degrees aged 21 or 22 and higher degrees at age 22 or 23 (Masters) or aged 24 - 25 (doctorates). Sixty-three PSTs aged 26 or over had work experience gained in science or other fields. Five females aged over 36 were changing career after raising a family. Older males were changing career from a range of previous roles, for example, from running a family engineering business, working in the chemical industry, or as administrators in government departments.

### ***PSTs’ misconceptions about basic chemical ideas***

The theoretical maximum number of responses to any probe was 179: in practice this was not achieved due to a variable small number of null or uncodeable responses. A summary of the main misconceptions found across the whole sample in each topic is provided in Table 2. Information about the probes is provided in Appendix 1.

[INSERT TABLE 2 ABOUT HERE]

### **Particle theory and change of state**

The probe “Atoms” investigated PSTs’ understanding of the physical properties of copper atoms. About 16% suggested that a single atom of copper, if visible to the naked eye, would be coloured, in the same way as a gross sample of the metal is seen as red-orange. In response to the question posed in “Particles”, “What is between the particles?” in a flask of gas about 10% of PSTs responded “air”. A similar proportion responded to “Boiling” by suggesting that the gas in bubbles of boiling water comprises a mixture of hydrogen and oxygen gases.

### **Conservation**

Three conservation questions were posed. “Solution”, asked PSTs to suggest the mass of a solution formed when 50 g salt dissolves in 200 g water. Fourteen PSTs (7.8%) suggested the mass would be less than 250 g for a variety of reasons: seven attributed mass loss to a gas being produced, suggesting misunderstanding of the chemical context of the question; four suggested loss due to evaporation or energy; and one associated loss with a new compound being formed. Two did not offer explanations.

“Phosphorus” probed PSTs’ thinking about whether or not a mass change occurs when a piece of phosphorus reacts with air in a sealed container. About 24% suggested that the mass would decrease, divided between twenty PSTs (11.2%) who reasoned a gas was produced (which presumably they thought had less mass than the starting reagents) and those suggesting the reaction represented loss of energy and therefore loss of mass.

“Precipitation” asked PSTs what the mass would be when two solutions were combined in one measuring cylinder, producing a precipitate. Thirty-one PSTs (17.3%) thought the



mass would be less than that of the starting materials – of these a majority related this to gas production, suggesting misunderstanding of the chemical reaction. Around 7%, however, thought the mass would increase because the solid precipitate had more mass than the original liquids.

### **Combustion reactions**

“Petrol” investigated PSTs’ views about the mass of exhaust gas relative to the mass of petrol put in the fuel tank of a car. About 20% of PSTs thought exhaust gases had less mass than the petrol, because mass was converted to energy (9.5%) or petrol gas weighed less than liquid (6.7%). Around 26% thought the mass of exhaust gas would equal the original mass of fuel, reasoning “what goes in must come out” (15.6%) or because petrol was burned or used up (7.3%). These responses suggest that almost half of the sample ignored the presence of oxygen in the system. “Methane” asked PSTs to explain where the energy came from when methane gas burns in air. About 31% suggested this was from bond breaking. Others, totalling 22.4%, used general, macroscopic terms, suggesting energy came from one of air, flame, oxygen or carbon (11.2%); the remainder attributed “heat energy” or the rearrangement of chemical bonds as the source (11.2%).

### **Mole calculations**

Three questions of increasing complexity probed PSTs’ abilities to carry out mole calculations. “Carbon” asked PSTs to estimate the mass of carbon dioxide produced when 24 g carbon is burned in 64 g oxygen gas, given a balanced equation for the reaction. About 11% gave answers such as 56, 176, 172 or 21 g, suggesting they did not understand the principles involved. “Iron sulfide” investigated the extent to which PSTs used reacting mass reasoning to anticipate excess sulfur in a reaction between two moles of iron and more than two moles of sulfur, given that these elements react in a 1:1 mole ratio. About 18% simply added the mass values of iron and sulfur together. Finally, “Power Station” followed on from “Carbon”, asking for an estimate of the mass of carbon dioxide generated by burning 1000 tonnes of high quality coal. About 6% suggested the mass would be less than 1000 tonnes.

### **Chemical bonding**

Four questions explored PSTs’ understandings of chemical bonding. “Methane molecules” asked for an explanation about why methane gas has the molecular formula  $\text{CH}_4$ . About 35% of PSTs answered in terms of “carbon forming four bonds”, suggesting this element was the dominant partner in bond formation. A further 7% used anthropomorphic language, attributing feelings or needs on the part of the atoms or elements to the process of forming a stable molecule. “Chlorides” probed understanding about intermolecular bonds, asking why, when a mixture of magnesium chloride (ionic bonding) and titanium(IV) chloride (covalent bonding) is heated, the vapour comprises titanium(IV) chloride molecules only. About 53% reasoned in terms of covalent bond strength compared to ionic bonding: 36% suggesting this was because covalent bonding is “weaker”, while 17% explained that covalent bonding was “stronger”.

The probe “Sodium and chlorine” investigated understandings about ionic bond formation. Around 31% simply explained that the two elements “react”, offering descriptive, macroscopic information only. About 27% offered answers demonstrating misunderstandings about particles, energy, or bonds involved, the most common notion being that “Breaking a chemical bond releases energy”. For example, PSTs suggested that when hot sodium reacts with chlorine gas bonds are broken, generating energy that is released to the environment.

Finally, the probe “Hydrogen chloride” asked PSTs what particles they thought would be present when water is added to a gas jar containing hydrogen chloride gas, resulting in hydrochloric acid formation. Nearly 60% failed to list any ions. Of these 24% listed hydrogen ( $H_2$ ) and chlorine ( $Cl_2$ ); about 18% added oxygen, “ $O_2$ ”, to these two gases making a list of three gases, while around 16% suggested hydrogen chloride molecules were present. A second part to the probe asked PSTs to explain how hydrogen gas forms when magnesium metal is added to hydrochloric acid: 16% used hydrogen chloride molecules in their answers.

### **Differences between subject specialist groups**

Table 2 shows the mean score differences as percentages for the five sub-tests of misconceptions probes observed between subject specialist groups. These data show that PSTs across all disciplines held most misconceptions about chemical bonding, combustion (open-system chemical reactions) and mole calculations, the topics normally taught to 14 - 16s. Chemistry specialists out-perform physicists and biologists in every category, although the margins vary from 0.4% (conservation) to 18.9% (chemical bonding). Overall data indicate that biologists averaged 53% ( $n=99$ ); chemists 65% ( $n=39$ ) and physicists 55% ( $n=29$ ). One-way ANOVA indicated significance at 0.005, confirming statistically that chemists have fewer misconceptions.

Probes about conservation of mass, taught to 11-14s, showed fewest misconceptions among all PSTs, suggesting this topic is more securely understood. In contrast, the probes exploring chemical bonding revealed the largest proportions of misconceptions across PSTs from all three disciplines. Biology and physics PSTs in particular held weak content knowledge about a number of basic chemical ideas, especially chemical bonding. General observations of their answers showed that some physicists tended to use over-complex reasoning, for example stressing “ $E=mc^2$ ” wherever possible. Some biologists showed a tendency to offer descriptive answers which were restatements of the question or used macroscopic perceptions of matter.

### ***PSTs’ preferences for teaching all sciences or their specialist subjects***

PSTs’ views about preferences for teaching their nominated science specialist subject, physics, chemistry or biology, rather than teaching all sciences, that is, working as a “specialist” or “generalist” science teacher are shown in Table 3.

[INSERT TABLE 3 ABOUT HERE]

Table 3 indicates that the responses of almost all PSTs could be categorised as Neutral Specialist (NS), Positive Specialist (PS), Neutral Generalist (NG) or Positive Generalist (PG). Only eleven gave other types of response patterns, such as strongly disagreeing with both statements, a viewpoint which is difficult to classify. Almost half were NS, suggesting that at this point, their limited teaching experience led to tentative agreement with teaching both their specialism and other sciences. PSTs divide more or less evenly between the other three categories, with almost identical numbers, amounting to 38% of the sample, in the most polarised PG and PS sub-groups, expressing clear perceptions of preferred roles.

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Subject specialist sub-groups (that is, physicists, chemists and biologists) show specific, consistent response patterns characteristic of each. These are: physicists appear polarised between NS and PG classifications, that is, they are either NS or PG. Chemists show the highest proportion of PSs. Biologists show the smallest proportion of PGs. Statistical tests revealed no background characteristics, such as age, degree class, gender or holding a higher degree linked with preference data.

### ***PSTs' confidence for teaching all sciences***

Data relating to PSTs' confidence are shown in Table 4.

[INSERT TABLE 4 ABOUT HERE]

Based on patterns of agreement, disagreement or neutrality, a majority of PSTs' responses divided into four categories shown in Figure 1. Table 4 shows that about 18% of PSTs are Super-confident (SC), suggesting self-belief in their ability to teach any science subject with little anxiety. An identical number are "Confident" (C), expressing a slightly lower degree of self-belief. Thus, around one-third of PSTs generally seem to express positive feelings about teaching all sciences. A similar figure, about 35%, were coded WC. While we cannot of course read their thoughts, this sub-group may be indicating that they were aware of the need to teach all subjects and would work at the skills and knowledge required. A smaller proportion expresses anxiety (29%, A). Members of this sub-group state they need to teach their specialism to feel confident, showing a lower level of confidence compared to other PSTs about teaching other sciences.

Fourteen PSTs' responses did not fit into these categories, for example, those who disagreed strongly with both statements whose confidence level could not be determined.

The specialism exhibiting the highest proportion of super-confident PSTs is chemistry, whereas only one physicist claimed super-confidence. The distribution between super-confidence and confidence, working confidence and anxious varies significantly (Chi-squared value 0.092) between the three specialist sub-groups: around 87% of physicists are either working confident or anxious; chemists are split roughly 50:50 between super-confident/confident and working confident/ anxious, while 57% of biologists are super-confident/ confident and 43% working confident/anxious. This suggests that one or more characteristics associated with physics PSTs pre-disposes them to feel markedly more anxious than others about outside specialism teaching

Chi-squared tests (significant at 5% level) showed that possession of a higher degree appears to confer confidence on PSTs: those with a higher degree are significantly more confident than those without. Inspection of the data shows that 59% of PSTs with higher degrees are SC or C, compared to only 31% of PSTs without higher degrees. Conversely, 69% of non-higher degree PSTs are WC or A, compared to 41% of those with higher degrees. Other factors, such as age, gender or degree class were not statistically significant in relation to confidence.

### **Semi-structured interview data: Three "types" of trainee**

Fifteen PSTs were interviewed. Excellent agreement was found between their personal characteristics shown in questionnaire responses and views expressed. PSTs were not alerted or informed about the results of the personal characteristics questionnaire at any

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time. Three PSTs are used to illustrate “types” that emerge from the data – background data are provided in Figure 3.

	Valerie	Matthew	Daniel
Background	Degree: Environmental biology 2:1 Higher degree: MRes Ecology Age 34 Female Specialism: biology	Degree: Physics 1 <sup>st</sup> class  Age 38 Male Specialism: physics	Degree Chemistry 3 <sup>rd</sup> class  Aged 24 Male Specialism: chemistry
Preferences	Neutral generalist	Positive specialist	Neutral specialist
Confidence	Confident	Anxious	Working Confident

Figure 3: Three “types” of trainee

Valerie exemplifies a confident biologist with a higher degree. In preparing lessons, she focused on using school-based resource materials rather than “learning” new subject knowledge for herself. She used the same approach regardless of subject, but was conscious of using more internet-based research for chemistry teaching. She noted:-

“The biology came back a lot quicker and easier and I was more confident in what I was talking about teaching in the lesson, but [I was teaching only] Y8 [age 12 – 13s] chemistry so it wasn’t that difficult but I still wanted to make sure I knew what I was talking about.”

Valerie experienced the pitfalls of being over-confident. She found that one class performed poorly in a test on respiration, a topic regarded as within her specialism:-

“I thought I had gone through the topic really thoroughly ... but a lot of them didn’t do as well in the end of topic test ... I would have thought that was one of the strengths of being a biologist getting the message across to them, but it didn’t necessarily seem to work...”

In contrast, Matthew is an example of an anxious physicist with a strong preference for teaching as a specialist. Matthew acknowledged at interview that teaching biology was “outside of my specialism, without a doubt”, noting in terms of his preparation that:-

“I did not feel as confident handling questions in biology” and  
“.. because my biology knowledge was so limited it made it more difficult for me to think of practical things to bring in ...”

He worked closely with biology specialist teachers in his teaching practice schools to help him prepare for teaching outside specialism. In contrast, for preparing to teach physics, Matthew said:-

“The only thing with physics was that I needed to know what they needed to know, but if there was something outside [that I could add] that then bringing it into the lesson wasn’t a problem”

When teaching within and outside specialism, Matthew found these contrasts:-

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Biology - "I could not have taught that lesson and made it a successful lesson without doing the background reading, I wouldn't have done it"

Physics – "When I felt the kids weren't grasping [a topic] I could tackle it from a different angle ... that was very limited for me with the biology and to some extent the chemistry".

Thus, his anxiety for teaching outside specialism led him to read more widely in order to learn the required subject knowledge. This reliance on carefully prepared material for outside specialism teaching was apparent in this comment about his biology lessons:-

"I feel that teaching outside specialism is better because to a certain extent I'm learning as the children are, so I can see it from their angle and there's no confusion about what they need to know..."

He noted different difficulties for teaching physics:-

"With physics it's a different ball game .. there were times I knew I was thinking quite high level stuff and then dumbing it down [i.e. simplifying a topic] to something they would understand and that sometimes made my job a bit harder ..."

That he was aware of having knowledge at a higher level than the students is perceptive, showing Matthew consciously made adjustments in order to teach at an appropriate level. His confidence to do this remained within the bounds of physics as a subject.

Thirdly, Daniel, a working confident chemist who was neutral about working outside specialism, reported doing "a vast amount more research" for teaching topics with which he wasn't familiar, continuing:-

"...I must admit in my delivery I did not feel as confident [as when teaching chemistry], especially answering students questions ... in a high ability year 9 set where you do get some excellent very perceptive questions, but I was able to answer them thankfully because I had done so much research.."

Daniel shows that he experienced positive outcomes, or mastery, from his biology teaching, which gave him confidence to continue. However, in terms of teaching outside specialism, Daniel found that he was:-

"... a lot less creative ... with the biology and physics ... that went down to confidence in the material, I went down much more traditional lines... unlike my chemistry where I used role plays and things like that .."

This had the effect on children's learning experiences of making lessons less interactive, as he explained:-

"... where I wasn't confident I tended to stay away from the more dynamic and active and more kinaesthetic areas, because I was really concerned about getting that core material down [in children's notebooks]..."

## **Cross-analysis of PSTs' preferences for specialist or generalist science teaching and their self-confidence**

Table 5 gives data showing cross-analysis of preference and confidence data. As might be expected, no PSTs giving PS responses are super-confident, while fifteen of the twenty-nine categorised as PS are anxious – this reinforces the finding that some PSTs have strong preferences for teaching their specialist subjects and are anxious about teaching other sciences. Inspection of Tables 4 and 5 together suggests that “anxious positive specialist” PSTs are likely to include more chemists and biologists than physicists. Eleven PSTs (mainly biologists and physicists) are “super-confident positive generalists” who are enthusiastic about teaching all sciences and believe in their personal capabilities to do this. About two-thirds of the most populous category, neutral specialists, tends to demonstrate working confident or anxious traits. A chi-squared test of the response pattern in Table 5 shows significance to less than 1%.

[INSERT TABLE 5 ABOUT HERE]

### ***Comparing misconceptions and personal characteristics***

Table 6 reports the mean percentage scores PSTs obtained in the five misconceptions areas classified by preference and confidence sub-groups. Reference values for the whole cohort and the specialist chemists are included. No significant differences are observed between any mean scores for preference or confidence sub-groups. This suggests that no preference or confidence disposition for teaching a specialist science or all sciences relates statistically with high or low results on the misconceptions test. Misconceptions-type answers are relatively evenly distributed across the four preference and confidence sub-groups. Thus, we can say reasonably that anxious PSTs’ content knowledge for teaching these topics is not markedly worse than that of their super-confident colleagues. Super-confident PSTs may teach chemistry believing that their knowledge is better than it really is, so their confidence may be misplaced. Table 6 also leads to the conclusion that a preference for specialist teaching also does not relate to higher quality content knowledge as measured by these probes. Positive specialists did not score markedly higher or lower than positive generalists in any of the five chemical topics.

[INSERT TABLE 6 ABOUT HERE]

One reason for the small differences in mean values in Table 6 is that PSTs of all specialisms are included in each preference or confidence sub-group. Thus, chemists, who in general scored higher values than other PSTs (Table 2), may skew sub-group mean values upwards towards those for their specialist group, obscuring differences.

In order to examine the impact of subject specialism more closely, Tables 7 and 8 present preference and confidence sub-group data for two misconceptions areas, Particle theory and change of state (taught to 11-14s) and chemical bonding (taught to 14 – 16s) respectively, divided by subject specialism.

[INSERT TABLE 7 ABOUT HERE]

Of course, small numbers in Tables 7 and 8 make artefacts in the data apparent, but useful patterns emerge nonetheless. For example, Table 7 shows that in responding to particle ideas, chemists do not score the highest mean values consistently – NG and PG biologists (setting aside the two high scoring NG and PG physicists) score more highly than the smaller numbers of NG and PG chemists. The NS biologists, numbering forty, score lowest

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of all. The PS chemists score the highest mean, which is a reasonable expectation for this group, but PS biologists and physicists also achieve good scores. Chemists mean values vary between 45 (NG) and 69 (PS), suggesting that the specialists held the best subject knowledge about this topic.

[INSERT TABLE 8 ABOUT HERE]

The confidence categories reveal a more consistent pattern. SC and C PSTs in all three specialist subjects score lower mean values than those coded WC and A. Even SC chemists score lower than anxious ones. Anxious physicists and biologists achieve higher mean values than anxious chemists. This suggests that for these topics, as indicated in discussion about Table 6, SC and C PSTs' confidence may be misplaced.

Table 8 gives specialist subject PSTs' mean values by preference and confidence sub-groups for chemical bonding. The data show consistently lower scores for biologists than chemists or physicists, supporting the observations made relating to raw misconceptions data discussed above (Table 2). Personal characteristics again support the statement that super-confidence and confidence in relation to content knowledge about this topic may in reality, be over-confidence, as the mean values achieved by PSTs in these categories in all disciplines are not markedly better than those of WC and A PSTs who may be more aware of their content knowledge weaknesses.

## **Discussion**

### **Pre-service science teachers' misconceptions about basic chemical ideas**

These science graduates exhibited misconceptions similar in nature to those of 14 -16 year olds found in earlier studies, most of which are well-known in the literature. It is possible, indeed, likely, that faulty reasoning results from their school, rather than university education. Thus, at no stage since leaving school have these misconceptions been challenged, lending support to the well-known notion (for example, Champagne, Gunstone & Klopfer, 1985) that such ideas resist change until prompted to do so. Significant here is that these are held by *science graduates* regarded as "*well-qualified*" for teaching science: and that almost all succeeded in becoming science teachers. They may now be in a position, unless remedial action has been taken, to perpetuate misunderstandings further on. The tendency to "describe" rather than "explain" in giving answers to difficult questions was also apparent, especially to chemical bonding questions, such as "Sodium and chlorine" to which many replied that "sodium and chlorine were reacting and forming a bond" or similar. This finding supports Taber's (2009) view that chemical bonding is a highly problematic subject to understand. PSTs giving this type of response may have recalled information they were told, or perhaps knew more but did not want the trouble of writing lengthy answers. The authors suspect that the truth lies with the former, rather than the latter– the quality of PSTs' responses probably reflects the teaching received during their school science courses. At the time these respondents were in secondary school (11 -16s), the most frequently taught 16+ science course (the General Certificate of Secondary Education, GCSE) featured all aspects of science compressed into two GCSEs, referred to in the UK as a "Double Award". Anecdotal evidence suggests that these courses offered little time to develop good conceptual understanding. (Note that while such "Double

Award” courses remain commonplace, higher proportions of GCSE students now take separate GCSEs in three sciences, one each in physics, chemistry and biology.) A separate trend, which began in earnest in the UK from the mid-1990s onwards, is the move towards science teachers teaching all subjects. As the introduction to this paper indicates, a lack of physical science graduates coming forward for teacher education over the last fifteen years has led to those with biological backgrounds dominating science teaching increasingly. Thus, as physics and chemistry specialists are scarce, biology graduates have to teach these subjects in many state-funded secondary schools. This position is current in the UK today. This paper contributes towards discussion of implications arising from these circumstances. Thus we suggest that the responses reported here may result from PSTs receiving inadequate science teaching in school.

### **Statistical relationships between PSTs’ misconceptions and academic and personal characteristics**

#### ***PSTs’ academic backgrounds***

These participants are regarded as “academically well-qualified” for teaching purposes, but in practice many may not have studied the chemical topics probed in this study for at least five or even up to twenty years. Even specialist chemists vary in their first degree subjects – some may not have studied an extensive range of chemistry courses in the final years of their degrees, but only spent a proportion of their time on this subject. Thus, PSTs’ responses to the misconceptions probes must be regarded as intuitive, and may not accurately reflect knowledge they would use if called upon to teach these topics. Some, at least, would realise their errors if these were pointed out (for example, the exclusion of oxygen in the combustion reaction questions) and, given more time to reflect, be able to recall how to carry out mole calculations; others would, knowing that chemistry was a weakness, learn the necessary material to ensure they taught accurately. Nonetheless, their responses to the probes represent a useful picture of the levels of knowledge demonstrated by a group of “good” science graduates, drawn randomly by adherence to common criteria for acceptance on to a postgraduate science teacher education programme. The chemical content knowledge probed was not “difficult”, drawing only on basic ideas that a competent science teacher may be expected to know and understand. As such, the responses reveal a surprisingly large number of misconceptions, suggesting that possession of a degree in science, and even in chemistry or a chemically-related subject, is no guarantee of good content knowledge for teaching the subject.

#### ***PSTs’ preference and confidence viewpoints***

Preferences for teaching as a specialist or generalist, and confidence for teaching within and outside specialism data were collected after a short period of full-time teaching practice. At this stage, PSTs’ opinions may not be fully formed about roles, so in responding to the preference statements the common “neutral specialist” stance is entirely reasonable. That science teachers are expected to teach all sciences up to 14 and often to GCSE (16 year olds) level is made clear prior to admission to the training programme, but the extent to which PSTs experience specialist / generalist teaching on teaching practice varies: some teach their specialism almost exclusively, while others may not do so at all in the first practice period. Preference and confidence data may be framed by variations in experience, as PSTs who taught their specialism may want to continue, or realise they would like to teach all sciences. Conversely, those who taught their non-specialist subjects will not form an opinion about specialist subject teaching from experience. However,



interview data, collected towards the end of the one-year course, suggests that preferences and confidence levels probed early on were unchanged— the sample interview data given above shows good alignment between stated views and questionnaire responses, and at no time did interviewees indicate their opinions had changed. Thus, on these parameters, our findings contrast with those of Ng, Nicholas and Williams (2010) who report significant changes in self-efficacy. Similarly, PSTs with extensive specialist subject teaching experiences may feel especially apprehensive about outside specialism teaching, while those who taught all sciences may have found the experience positive or negative. Such factors cannot be controlled, but in general, these data can be considered reliable, as PSTs were free to express personal opinions and the viewpoints represented honest reflections at the time.

Interview data suggests that preference and confidence viewpoints are based on deep-seated perceptions. PSTs can articulate their feelings about teaching within and outside specialism, drawing on prior experiences as a student, their subject knowledge and aspects of pedagogy (Author 1, 2009). There is reason, therefore to accept that the views expressed in response to these statements represent opinions fairly.

### ***Statistical relationships between misconceptions and personal characteristics***

The lack of any firm relationships between personal characteristics and misconceptions data is striking (Tables 6, 7 and 8) and intriguing. The poor performance of significant proportions of these graduates on many probes suggests gaps in content knowledge for teaching chemistry that need to be addressed before they can be regarded as truly “qualified to teach”. Hence, possession of a “good” science degree is not, of itself, a consistently accurate indicator that a pre-service teacher has the content knowledge required to teach chemistry up to the age of 16.

Reasons for the lack of correlation can be suggested. First, we must assume that if participants had been made aware of their misconceptions in chemistry prior to responding to the personal attributes questionnaire, their responses may have been different. Such a scenario would have probably prompted a greater number of “low confidence”-type answers. Thus, the data reported above arise simply because PSTs are not aware they hold any misconceptions. This is consistent with literature reported earlier (p 23) indicating that prompts are needed to stimulate conceptual change. Second, the data suggest current practices prevalent in chemistry teaching are unhelpful in forming secure conceptual understanding. Many probes were answered with descriptive and/or anthropomorphic statements which most likely were recalled from teaching, such as (paraphrasing) “ionic bonds are stronger than covalent bonds”; “carbon wants to form four bonds”; “metals and non-metals react together”; “metals displace hydrogen from acids”, or, “metals swap partners with hydrogen in acids”. Thus, these graduates have “learned chemistry” and justifiably *believe themselves to be knowledgeable*, without ever having considered underlying concepts, or being challenged about inaccurate ideas. Although this is speculation, the era in which respondents were educated (mainly in UK schools) is that of “Double Award” GCSE science, a 16+ course offering restricted input of knowledge of all three sciences and frequently taught by “science” rather than “specialist” teachers. We see the results: the PSTs may have been taught by non-chemists grappling with their own limited understanding of these ideas and grasping for phrases that cover basic examination needs. Nonetheless, the implication is that correcting steps are required to ensure this approach is not continued for future generations of school students. A third point arises from these two: that despite over twenty years of research illuminating misconceptions in

many aspects of chemistry, teaching still fails to ensure these are elucidated and eradicated amongst school students. Academic colleagues in university chemistry/science departments likewise seem not to explore weaknesses in understanding of underlying principles. Thus, these data point to failures to address chemistry misconceptions at fundamental levels, showing that weak understanding of even the most basic principles can be perpetuated to further generations. More positively, most PSTs realise that undertaking initial teacher education will involve revisiting science topics they last learned in school. The personal traits analysed here indicate how PSTs may self-prepare for teaching. Evidence suggests that super-confidence or confidence are the most “dangerous” stances in content knowledge terms. SC or C PSTs may not regard their content knowledge as weak, and teach, as did Valerie (p 19 – 20) without stopping to check their own understanding, or their students’ prior knowledge. Author 1’s earlier paper (2009) showed that super-confident PSTs exhibit qualities consistent with those described by Gurvitch and Metzler (2009), focusing on trying out various approaches in their lessons and being unafraid of innovation. Rice (2005) points out that poor content knowledge leads to teachers being unable to identify or challenge students’ misconceptions, and/or help students who are confused, or who raise an invalid question. Innovative activities are insufficient to guarantee good learning. Tables 4, 7 and 8 reveal that about 10% of a cohort may be super-confident biologists who may be over-confident about their chemistry knowledge.

“Safe” content knowledge stances are working confident or anxious. In this context, “safe” means that a WC or A pre-service teacher is likely to be aware of potential content knowledge weaknesses and knows these must be remedied prior to teaching, or will check content knowledge prior to teaching. Daniel and Matthew are examples – both described at interview the amount of “extra” work they did to prepare outside specialism lessons, and the impact this may have had on children’s learning. “Anxious” PSTs may be especially valuable, as they may have “defensive pessimism” traits (Merz & Swim, 2008). This leads them to finding ways of handling their anxiety to achieve positive outcomes. Physicists in this study tended to be more anxious than other specialists.

## **Conclusions, Limitations and Practical Relevance**

### ***Beginning to teach chemistry: are graduates prepared?***

The claims regarding specialist teachers with which this paper began appear to be justified. The content knowledge test used here shows that chemists exhibit superior understanding of chemistry concepts compared to other science graduates. Non-chemists hold more diverse misconceptions about basic chemical ideas, most notably in topics taught to 14-16s such as chemical bonding, mole calculations and open-system chemical reactions. The data show all PSTs’ content knowledge for teaching 11-14s is more secure than that for 14-16s. However, the study did not investigate the extent to which remedial activities designed to develop content knowledge during the PGCE prompted changes. As these are academically able graduates, there is a possibility that their understanding may have improved by the end of the course, so the position may not be so clear cut. An intervention study carrying out pre- and post-misconceptions and personal attributes tests either side of the subject knowledge, and content knowledge sessions offered in training would provide valuable insights. Explorations of PSTs’ teaching of chemistry topics and gathering of pedagogical content knowledge (PCK) data would add an additional dimension. Note too, that the “specialists are best” claim presumes they are available in equal measure. The reality is that a majority of pre-service science teachers are biologists. Specialists must also

## ***Beginning to teach chemistry***

explore student prior knowledge and know about instructional strategies to handle misconceptions. So, all recruits, regardless of scientific background and personal stance need better training about awareness of personal misconceptions, those of their students and what to do about them.

No specific connections are observed between personal characteristics and misconceptions: poor understanding is evenly distributed across personal profiles. Thus, these data support the findings of Gostev (2008). Our data suggest that amelioration of PSTs' content knowledge in chemistry is needed in order to remedy deficiencies in understanding. Personal qualities indicate a variety of stances. Further research could be carried out to elucidate these in more detail by devising a more thorough personal attributes questionnaire corroborated by interviews. PSTs with different stances could then be investigated in order to assess the impact these positions have on development of teacher knowledge base components such as SMK (including CK) and PCK. Involving school-based mentors may be helpful in this, as earlier research (Author 1, 2009 and p 19 - 21) pointed to the positive outcomes achieved by provision of extensive support to deliver successful outside specialism lessons.

### ***Limitations***

The study is limited by the fact that data were collected from one institution from graduates on entry and within three months of entry. As indicated above, PSTs' chemical knowledge may improve through the PGCE year through exposure to chemistry teaching and content knowledge sessions in the university. The data presented above are internally reliable in that consistent response patterns were generated among graduates recruited over four academic years.

The misconceptions data are limited to five basic chemistry topics, common to all 11-14 and 14 – 16 courses. Of course, further work could be carried out to explore the extent to which similar patterns emerge for other chemistry topics, as well as those in biology and physics.

The preference and confidence data rely on PSTs' responses to two pairs of statements, categorical variables, in a longer questionnaire. Although the authors are confident that the responses did reflect honest viewpoints at the time, PSTs were self-reflecting – no other information, such as reports from mentors or lesson observation data was collected to support or contradict their perceptions. Hence, findings must be regarded as tentative.

### ***Practical relevance***

These data show that possession of a “good” degree in a science subject does not automatically ensure that graduates entering the teaching profession possess good content knowledge for teaching chemistry. This supports the continued use of HEI-based sessions that help remedy content knowledge weaknesses. Our study also suggests that PSTs' misconceptions may have been acquired during their education. HEIs therefore have a role in ensuring that explicit teaching is received that does more than simply “describe” chemistry, but offers cognitive challenge in an attempt to prompt conceptual change. Ensuring that the new generation of science teachers has sound understanding of key scientific ideas is essential if the challenges presented by misconceptions are to be fully met.

Using personal characteristics to analyse trainee science teachers may also be useful. Work reviewed above (McNally, 2006) suggests ways in which emotional aspects of

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teaching could be combined with academic learning to enhance PSTs' experiences. Identification of sub-groups with different confidence stances may be valuable in helping PSTs develop greater awareness of the potential impact they may have in the classroom. Further work is needed to ensure that any identification is rigorous, so clear targeted support can be offered.

This paper offers tentative support for teaching chemistry by specialists: chemists in this study had fewest misconceptions and the strongest preference (by proportion) for being specialist teachers. However, as long as unequal proportions of chemists, biologists and physicists come forward for teacher education, making all PSTs aware of their personal characteristics, misconceptions and what to do about these during the training process is vital to help ensure future generations of students receive good, scientifically accurate chemical education.

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Subject specialism	Biology		Chemistry		Physics		Totals	
Number of PSTs	94	(55)	47	(27)	31	(18)	172	
Gender	62	32	25	22	6	25	93	(54) 79 (46)
Age								
21 – 25	45	22	10	6	5	18	60	(34) 46 (26)
26 – 30	8	7	8	6	0	4	16	(9) 17 (10)
31 – 35	5	1	2	6	0	1	7	(4) 8 (5)
36+	4	2	5	4	1	2	10	(6) 8 (5)
Degree class								
1 <sup>st</sup>	6	2	7	2	0	8	13	(8) 12 (7)
2:1	37	17	4	5	1	5	42	(24) 27(16)
2:2	15	10	12	10	3	10	30	(17) 30(17)
3 <sup>rd</sup> / pass	2	2	1	2	1	1	4	(2) 5 (3)
Other / Not stated	2	1	1	3	1	0	4	(2) 4 (2)
Higher degrees	9	7	9	9	0	2	18	(10) 18 (10)

N= 172 7 did not provide background data

Data presented as female, male. Data in parentheses are percentages

Table 1: Science PSTs' backgrounds: gender, age and degree classification shown with subject specialism

Chemical topic	Specialism	Number of respondents	Mean percentage score	Standard Deviation	Standard Error	Significance
Conservation of mass	Chemistry	39	73	32.6	5.2	0.210
	Biology	99	73	28.9	2.9	
	Physics	29	62	28.1	5.2	
	Total	167	71	29.8	2.3	
Particle theory and change of state	Chemistry	39	64	22.3	3.6	0.038
	Physics	29	61	18.3	3.4	
	Biology	99	54	22.6	2.3	
	Total	167	58	22.2	1.7	
Combustion reactions	Chemistry	36	71	33.0	5.5	0.006
	Biology	96	54	30.6	3.1	
	Physics	27	47	29.7	5.7	
	Total	159	56	31.8	2.5	
Mole calculations	Chemistry	37	74	32.5	5.3	0.011
	Physics	29	68	31.3	5.8	
	Biology	92	55	35.3	3.7	
	Total	158	62	34.8	2.8	
Chemical bonding	Chemistry	39	57	22.6	3.6	0.000
	Physics	29	46	21.0	3.9	
	Biology	98	41	18.9	1.9	
	Total	166	46	21.1	1.6	

Note: N varies from those in Table 1 due to inclusion of those not providing background data and because different numbers of PSTs responded to specific questions.

Table 2: Chemical misconceptions scores of science PSTs by subject specialism

## Beginning to teach chemistry

	Biologists		Chemists		Physicists		
	Number	Column %	Number	Column %	Number	Column %	Totals
Neutral specialist	40	50.6	17	45.9	13	52.0	70 (49.6)
Positive specialist	17	21.5	9	24.3	1	4.0	27 (19.1)
Neutral generalist	12	15.2	4	10.8	1	4.0	17 (12.1)
Positive generalist	10	12.7	7	18.9	10	40.0	27 (19.1)
Totals	79	100.0	37	99.9	25	100.0	141 (99.9)

Note: 11 PSTs' responses did not fit into these categories.

Table 3: PSTs' preferences for teaching all sciences ("generalist") or their specialist science ("specialist") by training specialism

## Beginning to teach chemistry

	Biologists		Chemists		Physicists		
Sub-group	Number	Column %	Number	Column %	Number	Column %	Totals
Super confident	14	17.9	10	27.8	1	4.2	<b>25 (18.1)</b>
Confident	19	24.4	4	11.1	2	8.3	<b>25 (18.1)</b>
Working confident	26	33.3	12	33.3	10	41.7	<b>48 (34.8)</b>
Anxious	19	24.4	10	27.8	11	45.8	<b>40 (29.0)</b>
<b>Totals</b>	78	100.0	36	100.0	24	100.0	<b>138 (100.0)</b>

14 PSTs' responses did not fit into these four categories.

Table 4: PSTs' confidence for teaching all sciences by teaching specialism

	Preference sub-group				
<b>Confidence sub-group</b>	Positive generalist (PG)	Neutral generalist (NG)	Neutral specialist (NS)	Positive specialist (PS)	<b>Totals</b>
Super confident (SC)	11 (7.9)	3	10 (7.2)	0	<b>24 (17.3)</b>
Confident (C)	5	3	13 (9.4)	5	<b>26 (18.7)</b>
Working confident (WC)	7	8	25 (18.0)	9	<b>49 (35.3)</b>
Anxious (A)	4	2	19 (13.7)	15 (10.8)	<b>40 (28.7)</b>
<b>Totals</b>	<b>27 (19.4)</b>	<b>16 (11.5)</b>	<b>67 (48.2)</b>	<b>29 (20.9)</b>	<b>139 (100.0)</b>

Numbers in parentheses are percentages.

Note that 13 PSTs' responses did not fall into categories that permitted cross-analysis.

Table 5: Cross-analysis of science PSTs' confidence and preferences for teaching all sciences

	<b>Mean scores</b>		<b>Preference sub-groups</b>					<b>Confidence sub-groups</b>				
<b>Chemical topic</b>	<b>Whole cohort N=179</b>	<b>Chemists N=36</b>	PS	NS	NG	PG	<b>Row mean</b>	SC	C	WC	A	<b>Row mean</b>
<b>Conservation of mass</b>	<b>71</b>	<b>73</b>	67	70	76	69	<b>71</b>	75	59	76	68	<b>70</b>
<b>Particle theory and change of state*</b>	<b>58</b>	<b>64</b>	64	57	58	58	<b>59</b>	55	52	59	64	<b>63</b>
<b>Combustion reactions</b>	<b>56</b>	<b>71</b>	53	55	54	55	<b>54</b>	58	49	60	55	<b>56</b>
<b>Mole calculations</b>	<b>62</b>	<b>74</b>	60	66	58	64	<b>62</b>	58	61	68	58	<b>61</b>
<b>Chemical bonding**</b>	<b>46</b>	<b>57</b>	49	45	39	43	<b>44</b>	43	41	45	45	<b>44</b>

N=139 for preference and confidence sub-group means

\* Data in this row are used in Table 7

\*\*Data in this row are used in Table 8

Table 6: Mean percentage scores on misconceptions probes for PSTs classified by personal characteristics

	Preference sub-groups				Row mean	Confidence sub-groups				Row mean
	PS	NS	NG	PG		SC	C	WC	A	
Whole sub-group	64 (n=27)	57 (70)	58 (17)	58 (27)	<b>59 (141)</b>	55 (25)	52 (25)	59 (48)	64 (40)	<b>58 (138)</b>
Chemists	69 (7)	65 (17)	45 (4)	53 (9)	<b>61 (37)</b>	57 (10)	38 (4)	68 (12)	62 (10)	<b>60 (36)</b>
Physicists	64 (10)	55 (13)	80 (1)	80 (1)	<b>61 (25)</b>	30 (1)	65 (2)	62 (10)	64 (11)	<b>62 (24)</b>
Biologists	61 (10)	54 (40)	60 (12)	59 (17)	<b>57 (79)</b>	56 (14)	54 (19)	53 (26)	65 (19)	<b>57 (78)</b>

Numbers in parentheses are n values

Table 7: Mean scores on particle theory and change of state sub-test arranged by PSTs' subject specialism and personal characteristics



## Beginning to teach chemistry

	Preference sub-groups				Row mean	Confidence sub-groups				Row mean
	PS	NS	NG	PG		SC	C	WC	A	
Whole sub-group	49 (n=27)	45 (68)	39 (17)	43 (27)	<b>45 (139)</b>	43 (25)	41 (25)	45 (48)	45 (38)	<b>44 (136)</b>
Chemists	48 (7)	61 (17)	47 (4)	51 (9)	<b>54 (37)</b>	50 (10)	47 (4)	62 (12)	46 (10)	<b>52 (36)</b>
Physicists	48 (10)	46 (13)	33 (1)	44 (1)	<b>46 (25)</b>	44 (1)	39 (2)	46 (10)	49 (11)	<b>47 (24)</b>
Biologists	51 (10)	38 (38)	37 (12)	39 (17)	<b>40 (77)</b>	38 (14)	40 (19)	37 (26)	42 (17)	<b>39 (76)</b>

Numbers in parentheses are n values

Table 8: Mean scores on chemical bonding sub-test arranged by PSTs' subject specialism and personal characteristics

**Appendix 1 Chemical misconceptions questions**

Sub-test	Question	Content
Conservation of mass	Solution	Is the mass of a solution the same, greater or less than the mass of solute + solvent?
	Phosphorus	When phosphorus and water are placed in a closed flask and heated by the Sun, a reaction occurs. Is the mass afterwards the same, greater or less than the starting mass?
	Precipitation	When two clear colourless solutions are combined, a precipitate forms. Is the mass after the reaction the same, greater or less than the starting mass?
Particle theory and change of state	Atoms	Is an atom of copper – coloured? Malleable? Ductile? Explain.
	Particles	Draw particles in a flask of air at room temperature, the same flask with air removed and the same flask cooled to liquefy the air (outlines of three flasks provided). Explain what is between the particles.
	Boiling	What is in the bubbles in boiling water? Explain how condensation forms on a window pane.
Chemical bonding	Methane molecules	Explain why methane forms compounds with the formula $\text{CH}_4$ , not $\text{CH}_3$ , $\text{CH}_2$ or $\text{CH}$ .
	Chlorides	Explain why the vapour above a mixture of titanium(IV) chloride and magnesium chloride comprises titanium(IV) chloride only.
	Sodium and chlorine	Explain what is happening when a piece of hot sodium is lowered into a gas jar of chlorine and white sodium chloride is spattered on the inside of the jar.
	Hydrogen chloride	What particles are present in hydrochloric acid? Explain how hydrogen gas forms when a piece of magnesium metal is lowered into hydrochloric acid
Mole calculations	Carbon	Estimate the mass of carbon dioxide produced when 24 g carbon is burned in 64 g oxygen gas (Ar values

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		and equation provided)
	Power Station	Estimate the mass of carbon dioxide generated by a power station burning 1000 tonnes of coal.
	Iron sulfide	What would you get when 112 g iron and 80 g sulfur are made to react? (Equation with 56 g iron and 32 g sulfur provided)
Combustion reactions	Petrol	Is the mass of exhaust gases produced from 50 kg petrol the same, greater or less than the mass of petrol? Explain.
	Methane	Why is a spark or match needed to get methane burning? Where does the energy come from when methane burns? (Equation for combustion of methane in oxygen provided)